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CODE VALIDATION STUDY FOR BASE FLOWS

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ABSTRACT

New and old rocket launch concepts recommend the clustering of motors for improved lift capability. The flowfield of the base region of the rocket is very complex and can contain high temperature plume gases. These hot gases can cause catastrophic problems if not adequately designed for. To assess the base region characteristics advanced computational fluid dynamics (CFD) is being used. As a precursor to these calculations the CFD code requires validation on base flows. The primary objective of this code validation study was to establish a high level of confidence in predicting base flows with the USA CFD code. USA has been extensively validated for fundamental flows and other applications. However, base heating flows have a number of unique characteristics so it was necessary to extend the existing validation for this class of problems.

In preparation for the planned NLS 1.5 Stage base heating analysis, six case sets were studied to extend the USA code validation data base. This presentation gives a cursive review of three of these cases. The cases presented include a 2D axi-symmetric study, a 3D real nozzle study, and a 3D multi-species study. The results of all the studies show good general agreement with data with no adjustments to the base numerical algorithms or physical models in the code. The study proved the capability of the USA code for modeling base flows within the accuracy of available data.

CODE VALIDATION STUDY FOR BASE FLOWS

BY

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BASE HEATING STUDY VALIDATION OBJECTIVE AND APPROACH

OBJECTIVE

- ESTABLISH HIGH CONFIDENCE LEVEL IN PREDICTING BASE FLOWS
- ASSESS AND QUANTIFY PERFORMANCE OF EXISTING NUMERICAL ALGORITHMS AND PHYSICAL MODELS

APPROACH

- EXTEND EXISTING USA CODE VALIDATION TO BASE HEATING FLOWS
- BUILD UPON USA CODE VALIDATION ALREADY ESTABLISHED UNDER NASP PROGRAM

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SIX CASE SETS COMPLETED TO EXTEND USA CODE VALIDATION FOR BASE HEATING ANALYSIS

AEDC	Tangent ogive cylinder with centered propulsive jet	1 Case
AGARD	Nozzle afterbody parametric experimental study	9 Cases
YF-12	2-D aft-facing steps in high Reynolds number flow	9 Cases
AEROSPIKE	3-D single-stage-to-orbit demonstrator model	2 Cases
UVA	University of Virginia normal and axial injection	2 Cases
RHYME	Hypersonic flow over 10° ramp/injector	1 Case

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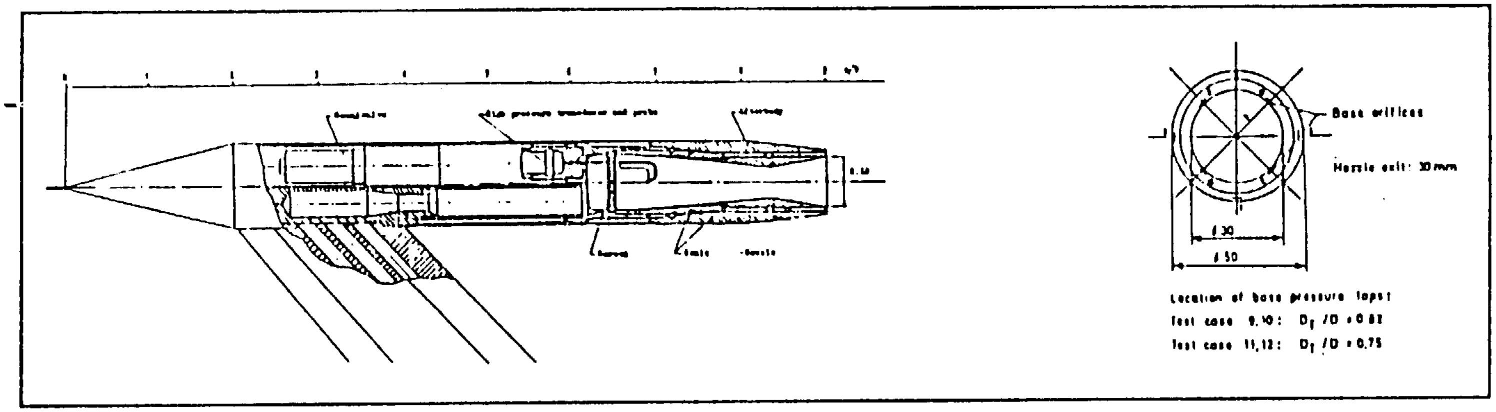
AGARD NOZZLE AFTERBODY CFD VALIDATION STUDY



- **TEST DATA: PRESSURE TAPS ON BASE**

References:

AGARD Advisory Report No. 26, "Report of The Working Group on Aerodynamics of Aircraft Afterbody," June 1986.L.E. Putnam And N.C., Bissinger, "Results of AGARD

L.E. Putnam and N.C., Bissinger, "Results of AGARD Assessment of Prediction Capabilities for Nozzle Afterbody Flows," AIAA Paper No. 85-1464.

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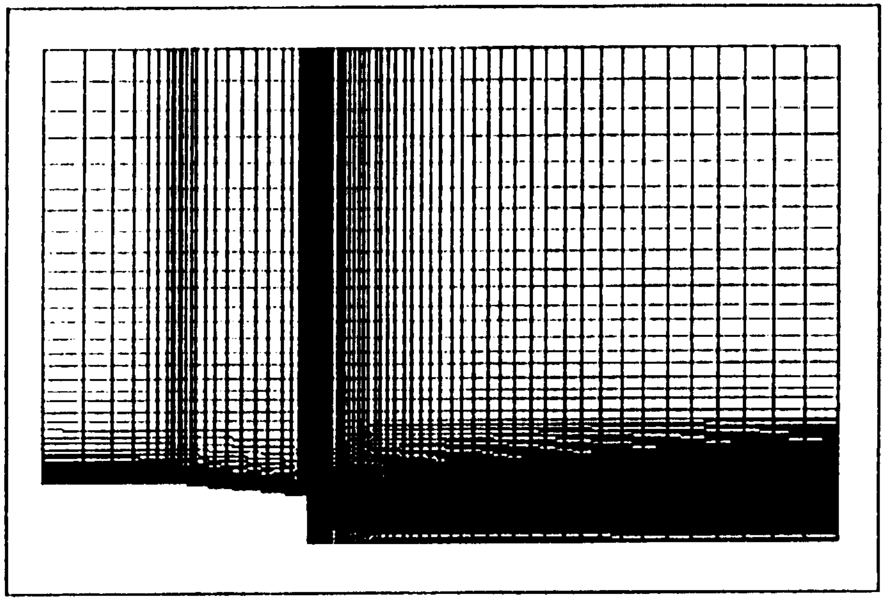
AGARD CFD MODELING APPROACH



- 2 ZONE GRID WITH CLUSTERING ABOUT SHEAR LAYERS
- FULL NAVIER-STOKES ANALYSIS
- AXISYMMETRIC
- PERFECT GAS
- BALDWIN-LOMAX TURBULENCE MODEL

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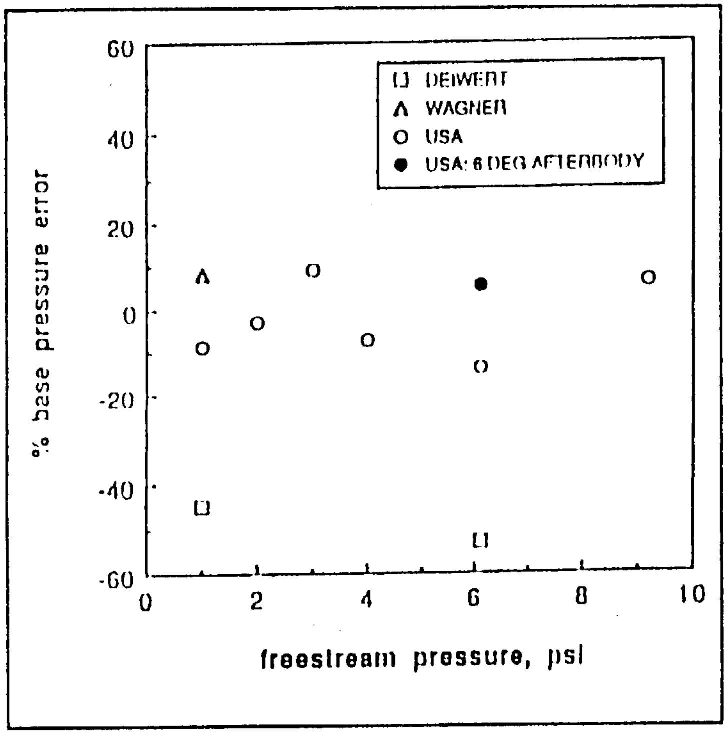
AGARD CFD VALIDATION STUDY CONCLUSIONS



- % DEVIATION OF USA PREDICTIONS (o, •) FROM MEASURED BASE PRESSURE DATA (FNS + BALDWIN-LOMAX) IS GENERALLY WITHIN 10% FOR THE 7 CASES COMPLETED
- WAGNER'S CALCULATION (Δ) FOR THE THE CASE REPORTED (FNS + BALDWIN-LOMAX) SHOWS SIMILAR LEVEL OF AGREEMENT
- DEIWERT'S CALCULATIONS (□) FOR THE 2 CASES REPORTED (THIN-LAYER NS + BALDWIN LOMAX) ARE OFF BY AS MUCH AS 55% PROBABLY DUE TO THE TLNS LIMITATION
- OVERALL AGREEMENT APPEARS TO BE GOOD AND THE KEY FLOW FEATURES AT THE BASE ARE CAPTURED

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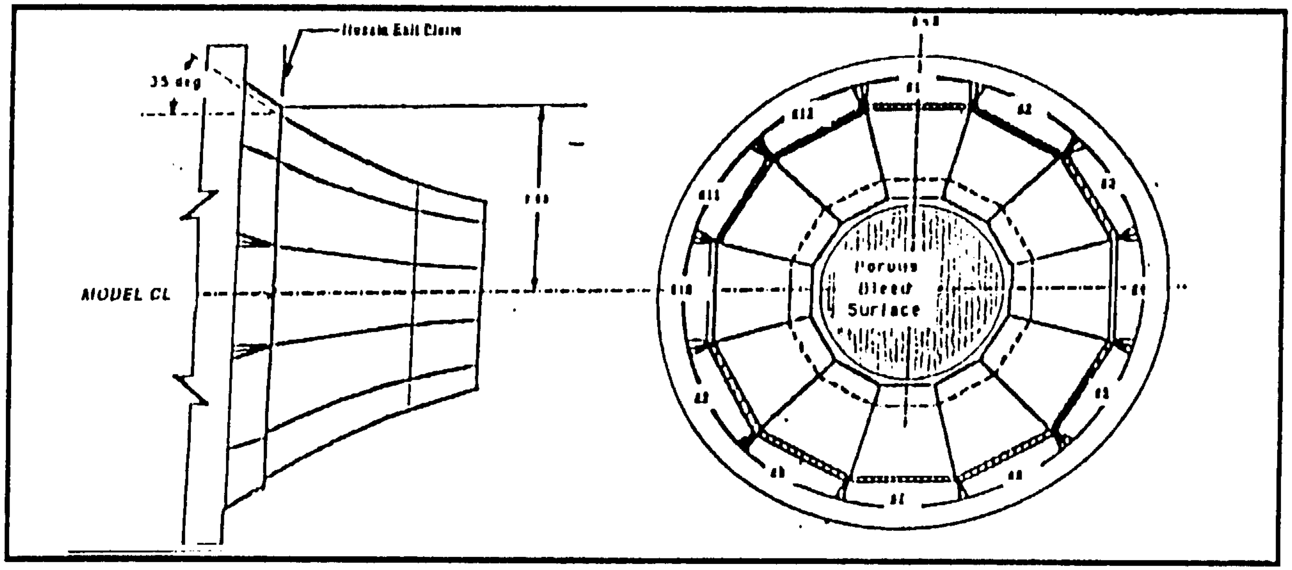
AEROSPIKE CFD VALIDATION STUDY



- **SSTO AEROSPIKE DEMONSTRATOR MODEL**
  - 12 MODULES, 11 THRUSTERS PER MODULE
- **TEST DATA**
- 37 PRESSURE TAPS ON NOZZLE SURFACE
- 21 PRESSURE TAPS ON BASE

Reference:

Kingsland, R.B., Petrilla, S., And Baker, W.M., "SSTO Aerospike Nozzle Demonstrator Test in the Fluidyne Channel No. 9 Test Facility," SSTO Pretest Conference, March 1991.

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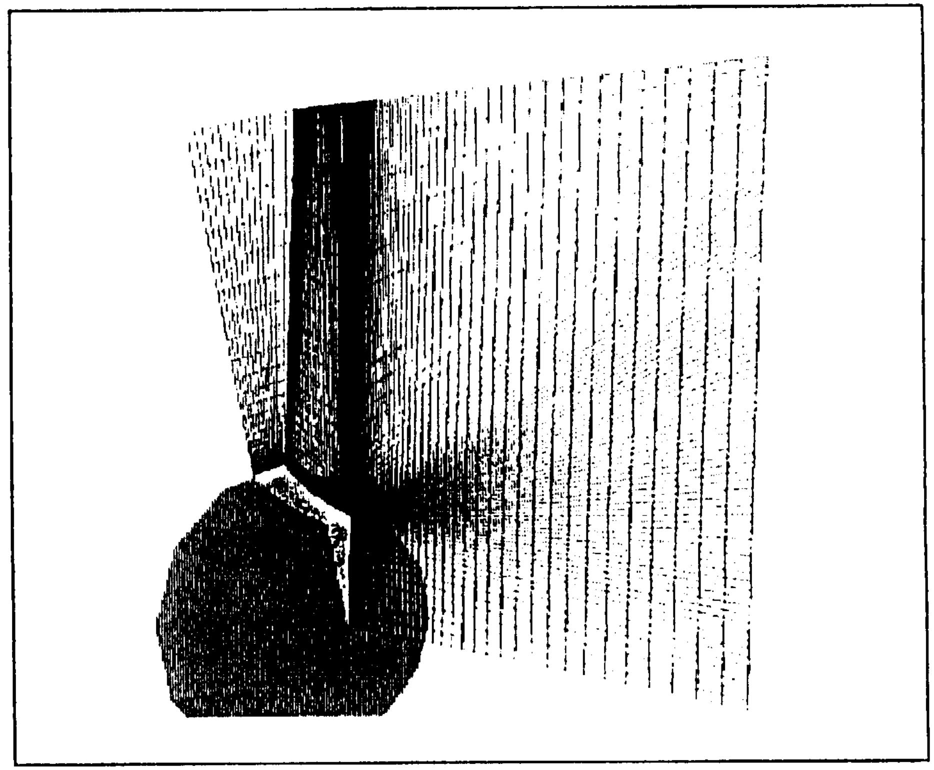
AEROSPIKE CFD MODELING APPROACH

- TWO COMPUTATIONAL ZONES
  - 1: UPSTREAM OF BASE
  - 2: DOWNSTREAM OF BASE
- 97,155 GRID POINTS



- 3-D NAVIER-STOKES ANALYSIS
- PERFECT GAS
- BALDWIN-LOMAX TURBULENCE MODEL

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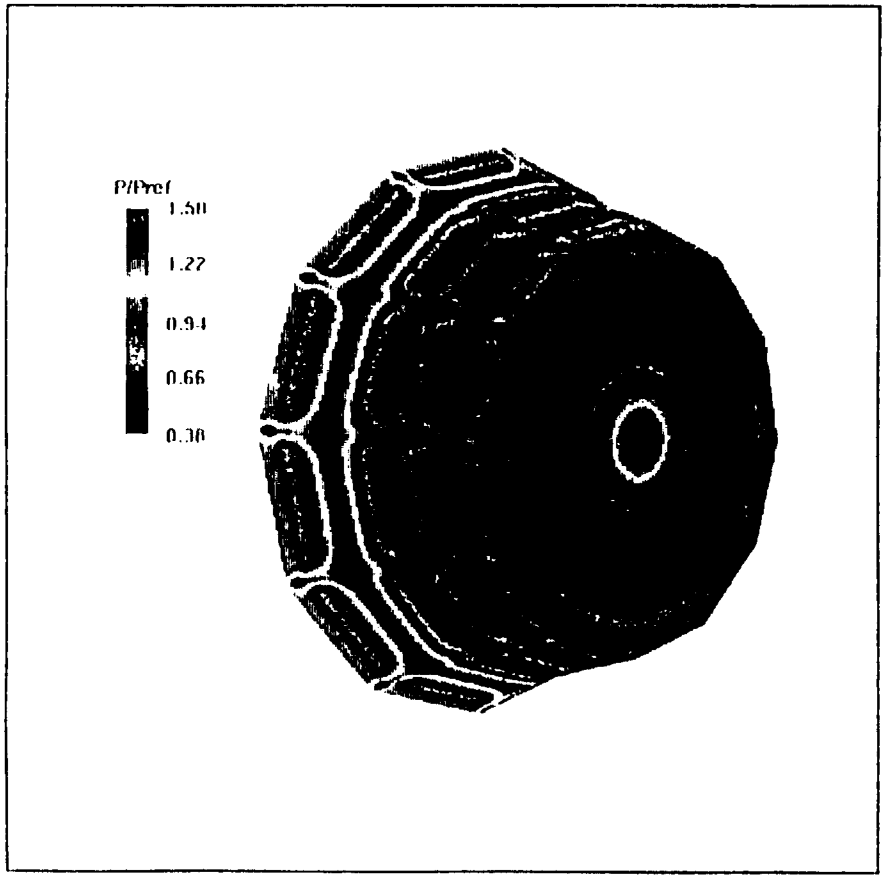
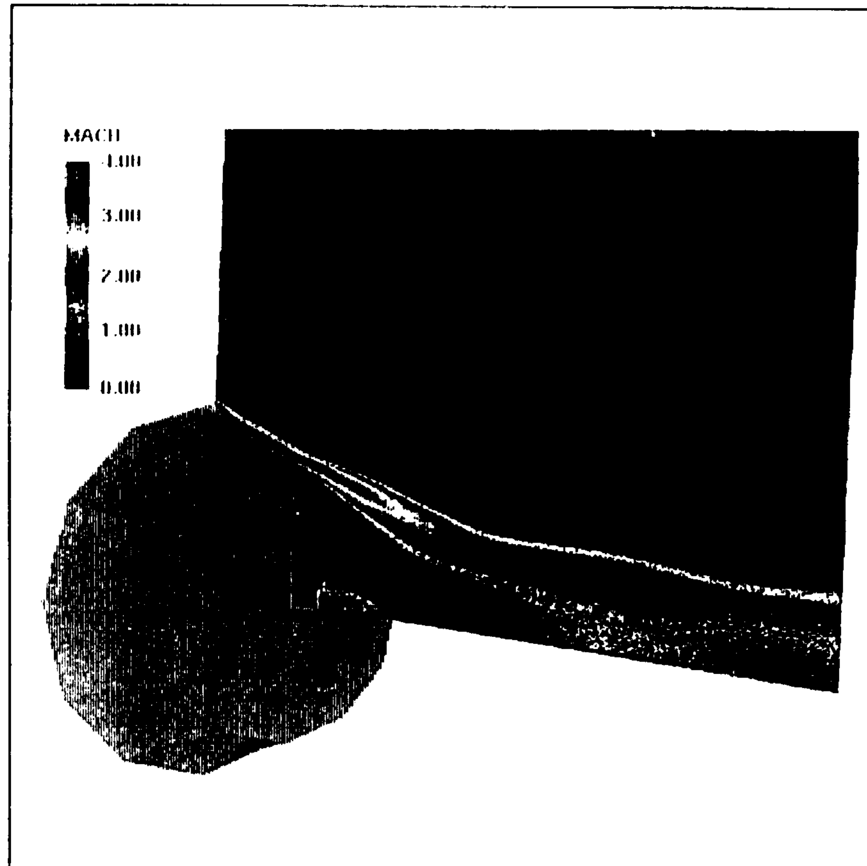
AEROSPIKE CFD ANALYSIS RESULTS





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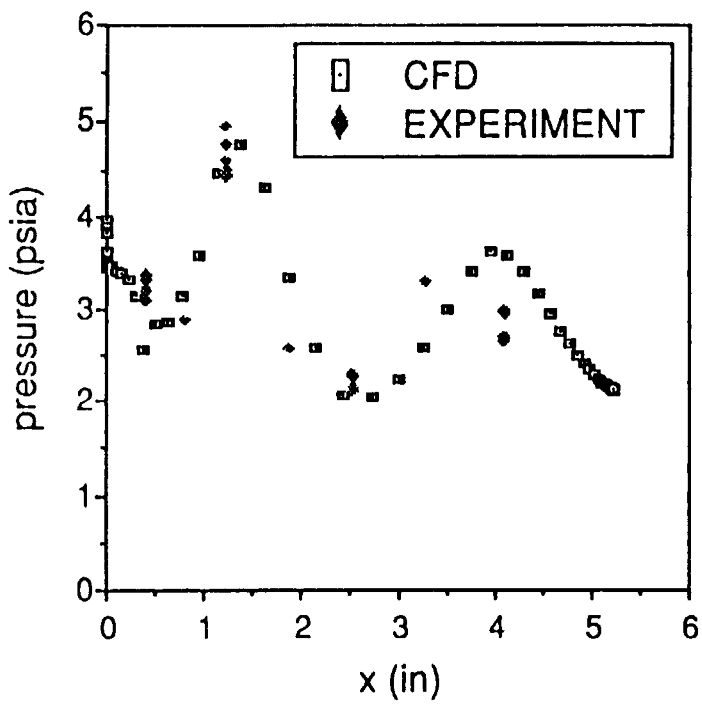
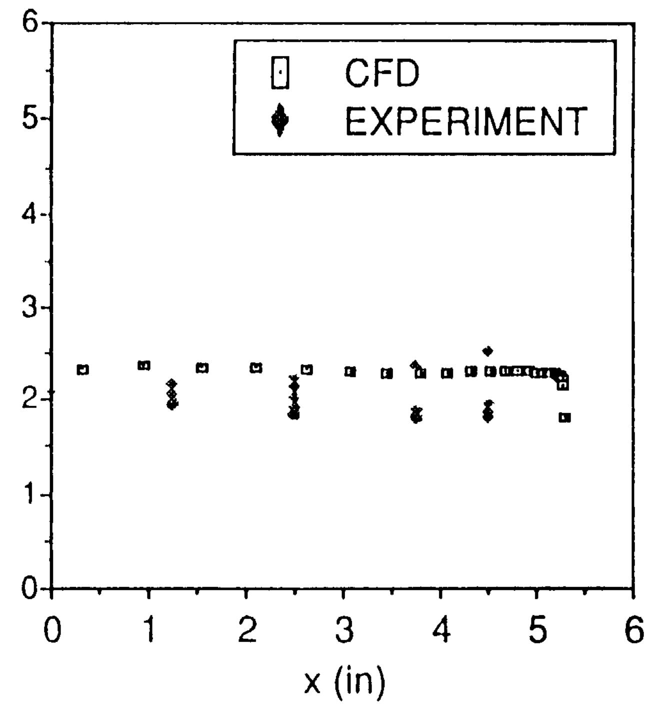
AEROSPIKE CFD ANALYSIS RESULTS (CONT'D)

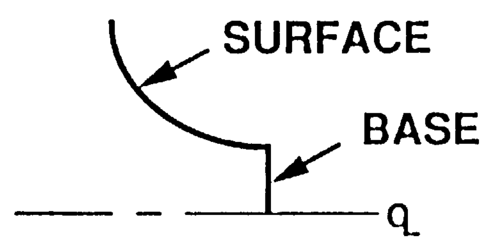
LOW PRESSURE RATIO CASE

BASE PRESSURE DISTRIBUTION



SURFACE PRESSURE DISTRIBÜTION





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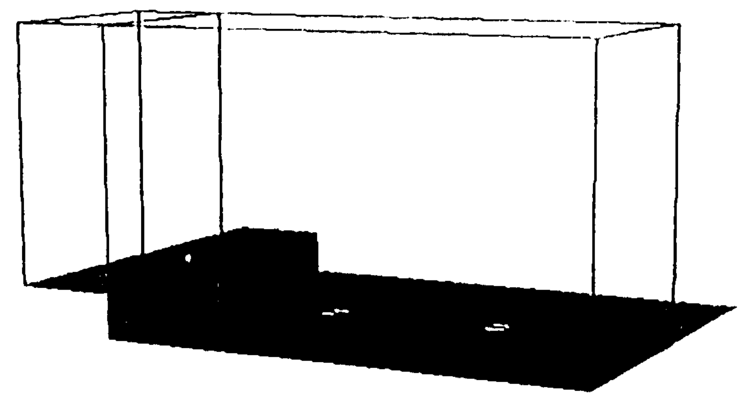
UVA CFD VALIDATION STUDY

FLOW GEOMETRY



- **TEST DATA**
  - PLIF MEASUREMENTS FOR P, V, AND T
  - INJECTANT CONCENTRATION

Reference:

J. McDaniel, D. Fletcher, R. Hartfield and S. Hallo, "Staged Transverse Injection Into Mach 2 Flow Behind a Rearward-Facing Step: A 3-D Compressible Test Case for Hypersonic Combustor Code Validation," AIAA-91-5071.

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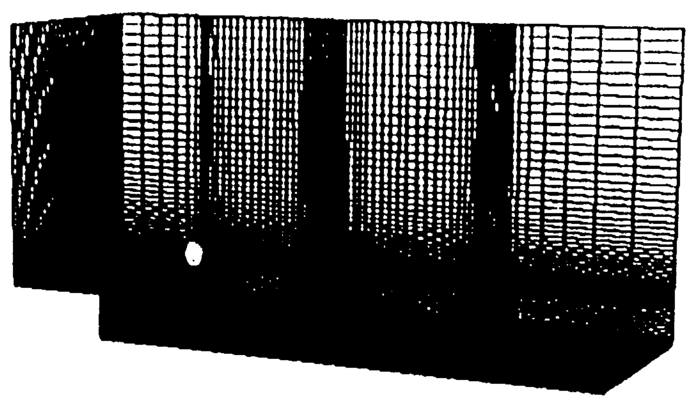
UVA CFD MODELING APPROACH

COMPUTATIONAL GRID



- TWO ZONE COMPUTATIONAL GRID WITH 171,532 POINTS
- 3-D NAVIER-STOKES ANALYSIS
- FROZEN CHEMISTRY WITH THREE SPECIES (O2, N2, AIR)
- 0-EQUATION GOLDBERG TURBULENCE MODEL

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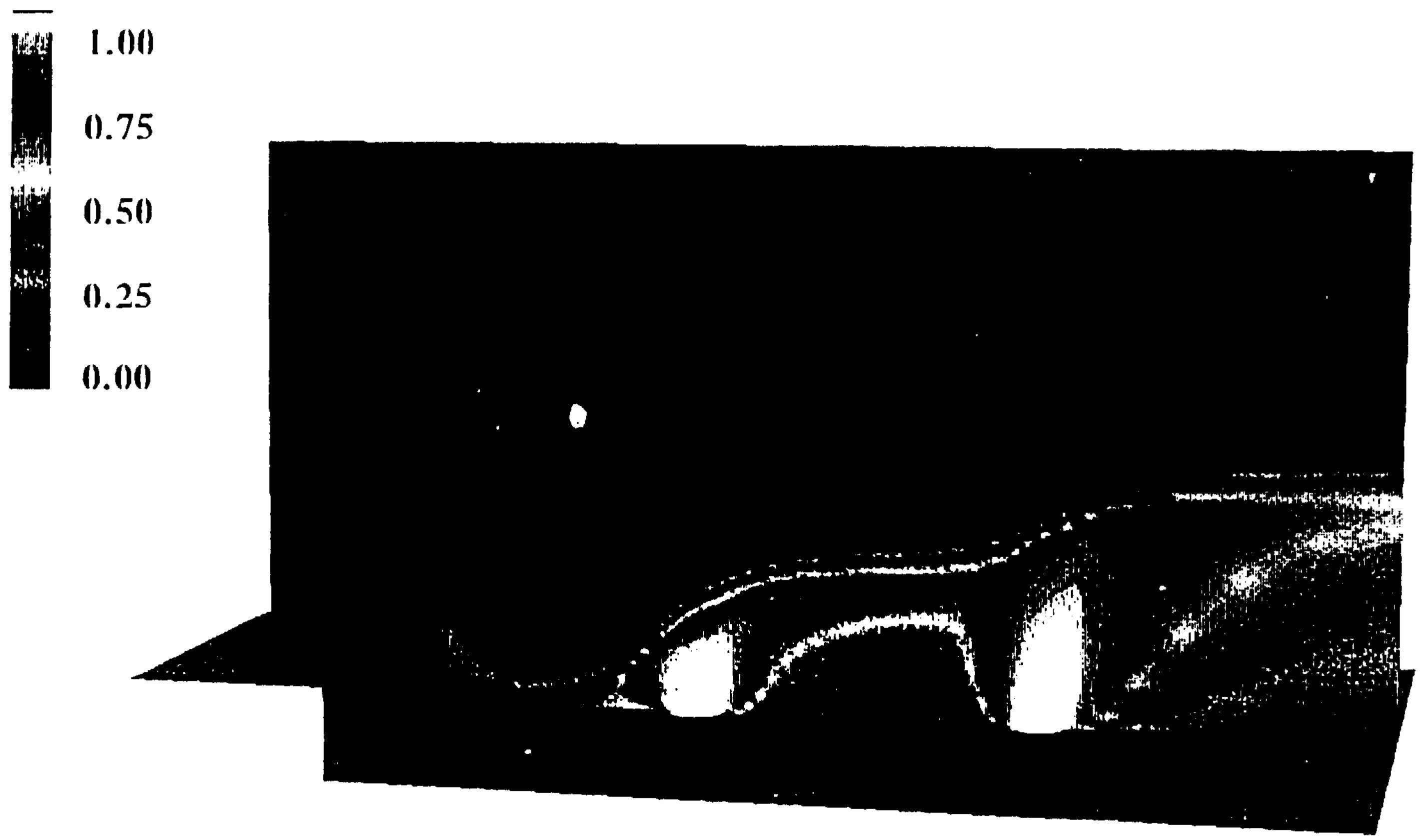
UVA CFD ANALYSIS RESULTS

CONCENTRATION CONTOURS OF INJECTANT



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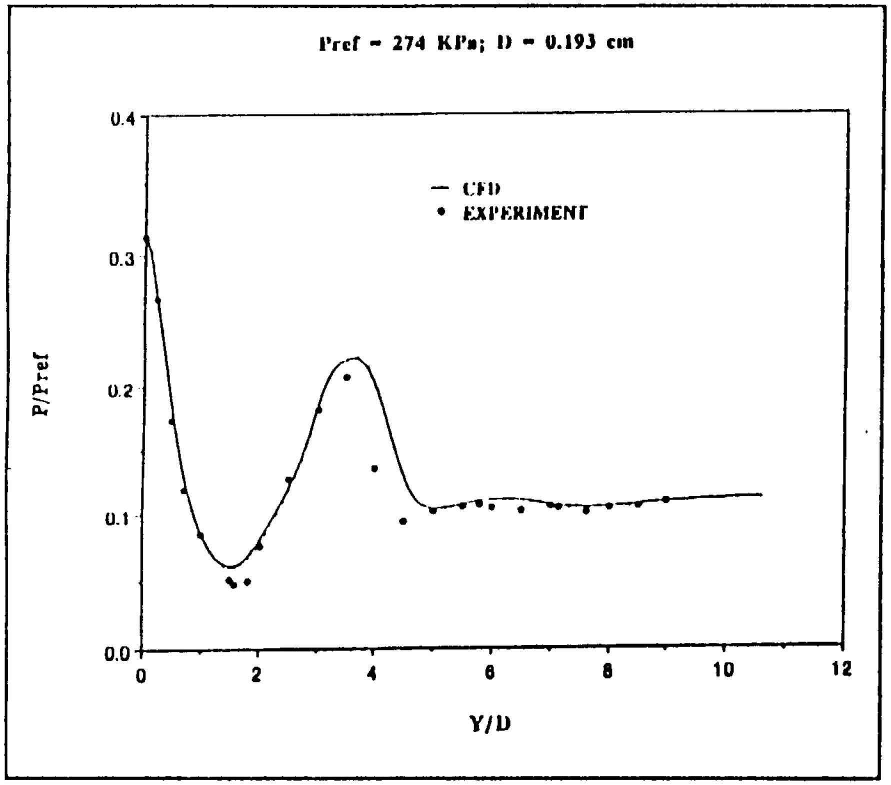
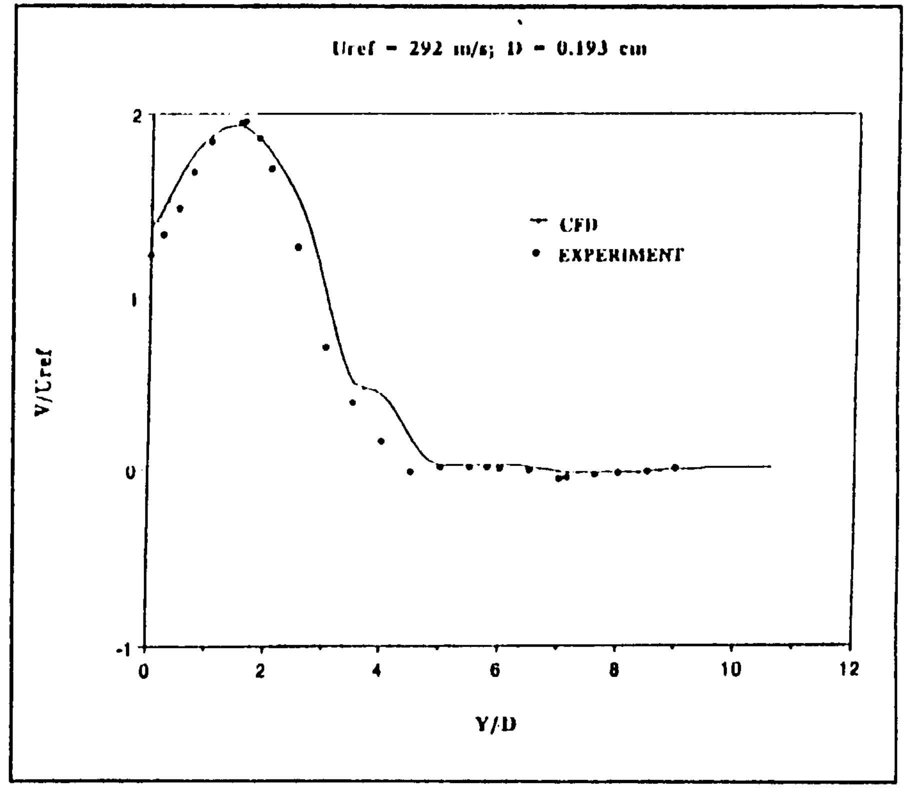
UVA CFD ANALYSIS RESULTS (CONT'D)

PRESSURE PROFILES AT CENTER OF 2ND JET (SYMMETRY PLANE)



NORMAL VELOCITY PROFILES AT CENTER OF 2ND JET (SYMMETRY PLANE)



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UVA CFD VALIDATION STUDY CONCLUSIONS

- **CALCULATIONS CAPTURE KEY FLOW FEATURES**
  - RECIRCULATION REGIONS BEHIND THE STEP AND AROUND THE INJECTORS
  - BOW AND BARREL SHOCKS
  - BASE PRESSURES
  - JET PENETRATION, SPREADING AND INTERACTION EFFECTS
- **PREDICTIONS SHOW GOOD AGREEMENT WITH TEST DATA**

CFD CODE VALIDATION ASSESSMENT

- **LEVEL OF AGREEMENT BETWEEN CALCULATIONS AND AVAILABLE DATA GENERALLY GOOD**
  - SOME CASES SHOW EXCELLENT AGREEMENT, OTHERS ARE GOOD TO ADEQUATE
  - OTHER THAN GRID REFINEMENT NO "ADJUSTMENTS" WERE MADE EITHER IN THE NUMERICAL ALGORITHMS OR PHYSICAL MODELS TO ACHIEVE BETTER AGREEMENT
  - MODELS USED IN THE VALIDATION WERE RESTRICTED TO THE SAME MODELS TO BE USED IN THE NLS CALCULATIONS
- **THERE IS A NEED FOR MORE CAREFULLY DESIGNED AND CONDUCTED EXPERIMENTS FOR CODE VALIDATION IN THE BASE HEATING AREA**

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